US Reactors for Antineutrino Experiments

Reactor facilities operated by US national laboratories and private utilities offer unique opportunities for a definitive search for neutrino oscillations at very short baselines, a precision measurement of the reactor $\overline{\nu}_e$ flux and spectrum from highly enriched uranium (HEU) fuel, studies towards the detection of coherent scattering, and $\overline{\nu}_e$ detector development for reactor monitoring and safeguard applications. Reactors are a flavor-pure source of antineutrinos and a unique laboratory for the study of neutrino properties and flavor transformation. Reactor antineutrinos have been key to a number of discoveries including the first observation of the electron antineutrino [1], the observation of electron antineutrino disappearance [2], and the recent measurements of the neutrino mixing angle θ_{13} [3–5]. Reactor $\overline{\nu}_e$ are also used in searches for a neutrino magnetic moment and coherent scattering. R&D is underway to use the flux of $\overline{\nu}_e$ for near-field (<100 m) monitoring of the power and fissile content of nuclear reactors [6] by measuring the time-dependence of the reactor antineutrino flux and spectra. Experiments with reactor antineutrinos leverage the long-standing expertise of US groups in this field. Figure 1 summarizes the accessible baselines of reactors in use and under consideration for experiments and provides a comparison of core dimension, geometry, and thermal power.

The National Institute of Standards and Technology (NIST) [8], Oak Ridge National Laboratory (ORNL) [9], and Idaho National Laboratory (INL) [10] operate powerful, compact research reactors for fundamental and applied research and provide user support for external scientific users. Research reactors provide a controlled research environment and maintain state-of-the-art reactor and neutron simulations. A several-ton scale neutrino experiment at distances of $\mathcal{O}(10\,\mathrm{m})$ is within the scope of experiments typically mounted at these facilities. The National Bureau of Standard Reactor (NBSR) at NIST, the High Flux Isotope Reactor (HFIR) at ORNL, and the Advanced Test Reactor (ATR) at INL have identified potential sites for the deployment of a compact $\overline{\nu}_e$ detector at distances between 4-13 m, 6-8 m, and 12-20 m from the reactor cores, respectively [14]. Studies of reactor correlated and cosmogenic background rates are planned for these locations. NIST offers the opportunity of a $\overline{\nu}_e$ flux and spectrum measurement at the closest distance yet measured while HFIR and ATR offer superb power for their very compact cores.

In addition to these research reactors the commercial SONGS reactors, with a deployment site at 24 m baseline, have been used for years for the development and operation of applied antineutrino detectors [15]. While SONGS' larger core limits sensitivity to $\overline{\nu}_e$ oscillations at neutrino mass splittings $>1\,\mathrm{eV}^2$, the high antineutrino flux and available overburden make it useful for detector development and coherent scattering studies. Furthermore, precision measurement of the $\overline{\nu}_e$ spectrum at the LEU-fueled SONGS core may help further constrain flux prediction uncertainties and improve our understanding of the evolution of reactor cores, especially when combined with a similar measurement of a static HEU core at a research reactor. In addition to the short baseline efforts described above, US reactor facilities could act as neutrino sources for studies at longer baselines, like the planned WATCHMAN effort to perform a demonstration of reactor monitoring at km distances.

US reactors are a unique, flavor-pure source of $\overline{\nu}_e$ for ton-scale experiments at distances between ∼4-24 m. Developing experimental capabilities at a US reactors provides an opportunity for a US-based program of very short baseline neutrino experiments with significant potential for fundamental discovery as well as applied instrumentation development at both short and long baselines.

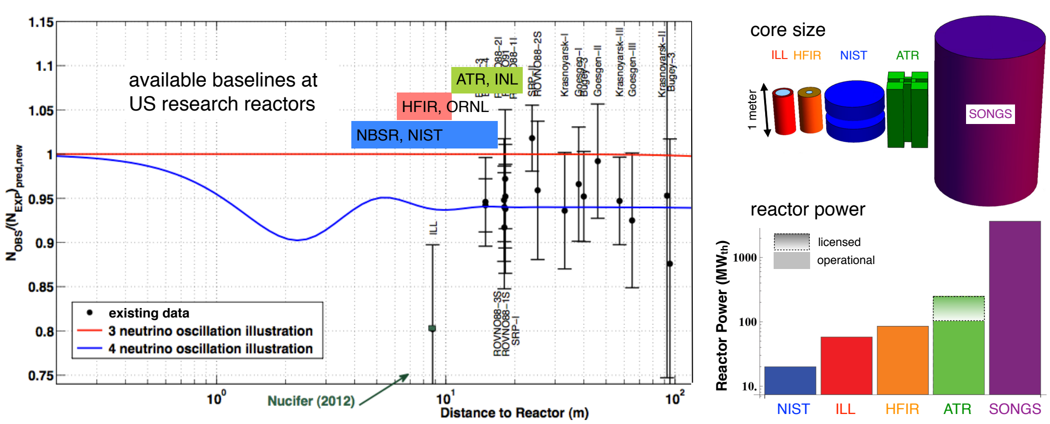

FIG. 1: Left: Reactor $\overline{\nu}_e$ flux measurements in reactor experiments up to ∼100 m baseline. Existing measurements are shown in black. The blue, red, and green bands indicate the distances at which new experiments at NBSR, HFIR, or ATR are feasible. Figure adapted from [7]. Right: Comparison of the size and power of several reactors cores. For ATR, both the typical operating power and the higher, licensed power are shown. Figures from [16]

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I. EXPERIMENTS AT US REACTORS – INTEREST GROUP

Z. Djurcic
Argonne National Laboratory, Argonne, IL 60439

S. Hans, M. Yeh
Chemistry Department, Brookhaven National Laboratory, Upton, NY 11973

E. Blucher, J.I. Collar
Physics Department, University of Chicago, Chicago, IL 60637

R. Johnson, B.R. Littlejohn
Physics Department, University of Cincinnati, Cincinnati, OH 45221

K. Scholberg
Department of Physics. Duke University, Durham, NC 27708

T. Allen, S. Morrell
ATR National Scientific User Facility, Idaho National Laboratory, Idaho Falls, ID 83401

J.G. Learned, J. Maricic
University of Hawaii, Honolulu, Hawaii 96822

A. Bernstein, N. Bowden, T. Classen, S. Dazeley, G. Keefer and M. Sweany
Physics Division, Lawrence Livermore National Laboratory, Livermore, CA 94550

T.J. Langford
University of Maryland, College Park, MD 20742

H.P. Mumm, J.S. Nico, R.E. Williams
National Institute of Standards and Technology, Gaithersburg, MD 20899

R. Henning
Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599 and Triangle Universities Nuclear Laboratory, Durham NC 27710

C. Bryan, D. Dean, Y. Efremenko, D. Radford,
Oak Ridge National Laboratory, Oak Ridge, TN 37831

D. Reyna
Sandia National Laboratories, Livermore CA 94550

P. Huber, J.M. Link, C .Mariani
Center for Neutrino Physics, Virginia Tech, Blacksburg, VA 24061

A.B. Balantekin, H.R. Band, J.C. Cherwinka, K.M. Heeger, W. Pettus, D. Webber
Physics Department, University of Wisconsin, Madison, WI 53706

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